1997 Queen Conch (*Strombus gigas*) Abundance Survey and Potential Yield Estimates for Pedro Bank, Jamaica

Alexander Tewfik[1] & Richard S. Appeldoorn[2]

[1] Center for Marine Resource Studies, South Caicos, TCI
[2] Dept. of Marine Sciences, Univ. of Puerto Rico

Final Draft Report
March 14, 1998

Fisheries Division
Ministry of Agriculture
Kingston, Jamaica

1.0 Introduction

Queen conch (*Strombus gigas*) populations occur in many areas of the Caribbean and they have long been considered one of the most valuable resources to many nations with some fisheries dating back to prehistoric times (Brownell et al 1977, Berg and Olsen 1989). Recent estimates of total harvest within the region range from 4000 MT (Appeldoorn 1994a) to 6000 MT (Tewfik 1997), however the vast majority of these conch stocks are considered fully or overexploited.

Although Jamaica had not traditionally been known for conch exploitation, large exports of conch have been coming from the island since 1991. The majority (approx. 95%) of this exploitation has come from Pedro Bank (Figure 1) off the islands' southern coast. As a result Jamaica has been considered the top producer of conch in the Caribbean since that time (Chakallal and Cochrane 1996) with mean annual export figures of 2045 MT (Figure 2). Given: **(1)** the importance of the conch to the local fisheries sector, with both finfish and lobster at low abundances; **(2)** the international protection afforded by the listing of *S. gigas* by CITES (Convention for the International Trade in Endangered Species) under appendix II (potentially threatened); and **(3)** the value of conch on the world market (US $60 million per annum), the importance of protecting the resource for the present and future generations becomes paramount. As a result the Fisheries Division has initiated several studies to provide a more complete understanding of the Pedro Bank conch stocks including: Mahon et al (1992); Appeldoorn (1995); Tewfik (1996); and Kong (1997).

The present conch survey is the second one of its kind. The details of the first survey, which occurred in November 1994, can be seen in Appeldoorn (1995) and Tewfik (1996). At that time the mean densities (number/ha) of conch were found to be much higher than reported from other areas in the Caribbean (Artisinal zone, 89 conch/ha; 10-20 m, 204 conch/ha; 20-30 m 277 conch/ha). The majority of the population was concentrated as normal (N) and stoned (S) adults; Artisinal zone, 73 conch/ha (82%); 10-20 m, 152 conch/ha (75%); 20-30 m 203 conch/ha (73%). Based on those observations mean maximum sustainable yields (MSY) were subsequently estimated using various models and ranged from 1398 - 1818 MT (Appeldoorn 1995) and 834 - 1800 MT (Tewfik 1996). The actual quotas for total catch were set substantially higher (2000 MT) than mean MSY figures and were to be reduced by 100 MT every year thereafter. The rational behind this was that the amount of exploitable biomass (N+S) was so high that the economic impact of reduced quotas could be spread out over time without decreasing exploitable biomass densities below levels necessary to maintain production. A second conch survey was mandated to confirm the impact on the fishery as well as examine important questions on recruitment rates and associated variations. It should be noted that poaching from the stock was suspected to be high and this loss was not subtracted from the total quota.

1.1 Purpose & Objectives

The overall purpose of this study was to gather the most current data on the Pedro Bank conch stock and make conclusions, incorporating the findings of earlier studies, for the continued proper management of the resource. In order to satisfy this overall purpose several specific objectives were addressed:

1) Estimates of population density (number/ha) and abundance (total population)
2) Description of population structure (size/age)
3) Estimates of population density by habitats and water depth
4) Estimates of recent exploitation levels
5) Estimates of recent and future recruitment
6) Estimates of maximum sustainable yields

2.0 Material & Methods

2.1 Study Site

Pedro Bank is a large submarine plateau which lies approximately 70 km south-west of Jamaica in the region between latitude 16°42'N and 17°39'N and longitude 77°19'W and 79°02'W (Figure 1). Deep channels, exceeding 1000 m separate the Bank from Jamaica and south-westerly shoals and banks. Pedro Bank, for depths less than 50 metres where the edge drops away rapidly, has an area of 8040 km^2, a maximum length of 168 km, a maximum width of 83 km in the west, a circumference of 590 km, and a mean depth of 24.5 m (Munro and Thompson 1973). The Pedro Bank was surveyed by British Naval Hydrographic ships Fox and Fawn in 1970 and detailed charts for navigation are available (British Admiralty chart no. 260). The bank gradually deepens in a northwesterly direction and is shallowest in the southern and southeastern areas (Figure 1). These shallow regions face into the Caribbean current and have well developed reefs. The ecological features of the bank are poorly known, including the extent of seagrass and algae cover, because of extremely limited scientific diving observations in the region. Diving conditions are difficult because of strong currents, rough seas, and abundant sharks (Munro and Thompson 1973).

The Bank has a mean sea surface temperature of 27oC with a seasonal variation of +/- 1oC, a tidal range of 0.33 m, and a mean salinity of 35 ppt which is presumed to be slightly higher in shallow water areas (Dolan 1972). Dolan (1972) made an extensive survey of the recent distribution of sediments on the Pedro Bank. Three distinct habitat types exist based on characteristic topography and sediment type; **(1)** Shallow reefs with irregular profiles that coincide with the shallowest areas, **(2)** Reef areas which have a more regular profile than shallow reefs and are characterized by sandy bottom with frequent isolated patch reefs, and **(3)** Sand blanket which composes two thirds of the bank and is made up of carbonate, biogenic, and sand detritus.

2.2 Survey Techniques & Analysis

For the purposes of this second abundance survey Pedro Bank was stratified into three zones defined primarily by management considerations (Figure 1). The Artisinal zone (ART) comprised an area of approximately 37 000 hectares and was represented by five study sites. It is the zone in closest proximity to the Pedro cays, includes all of the area of less than 10 m in depth as well as a small area of 10-20 m in depth (not included in this second zone), and represents the region that has the longest history of conch fishing on the bank. The second zone was the region of 10-20 m in depth outside the Artisinal zone that represented the main region of activity for the commercial vessels since 1991. It comprised an area of approximately 201 700 ha and was represented by 17 study sites. The third zone was the region of greater than 20 m in depth, includes the region of 20-30 m (370 000 ha) used in the first abundance survey (Appeldoorn 1995) and regions deeper than 30 m. This third zone was not assessed due primarily to budget and subsequent field time constraints. The 5 Artisinal and 17 10-20 m sites assessed were randomly chosen from the previous 7 Artisinal and 40 10-20 m sites used during the 1994 survey (Appeldoorn 1995). The emphasis of the survey again was to assess the area of primary importance to the commercial fleet (10-20 m zone).

The visual survey was conducted from the Jamaican Fisheries vessel M/V Dolphin over a ten day period during mid-November 1997. Study sites were located using a Global Positioning System to the nearest minute of the original coordinates used during the 1994 survey. Once anchored at the site two teams of two divers were deployed. The pairs of divers swam 3 x 100 m transects (sampled 300 m^2), in one of the four cardinal directions. The transects were begun in close proximity of the support vessel. The first diver in a pair swam out a 100 m long tape anchored by a 1kg weight at the start point. The other diver followed searching for all conch on or buried in the sediment within 1.5 m (using a 3 m long PVC pole as a guide) on either side of the tape. The number of transects completed depended largely on depth of the site and subsequent air consumption.

There are several difficulties in ageing conch directly: the change in growth from shell length in juveniles to shell lip thickness in adults, bioerosion of shell in older adults which may equal or exceed shell lip growth, and spatial variations in shell growth rates due to conditions of habitat (water depth, latitude, food availability) (Alcolado 1976, Appeldoorn 1988a, Stoner and Sandt 1992). As a result conch were categorized into six groups using mean shell lengths (juveniles) and shell morphologies (sub-adult, normal & stoned adults) observed in the field (Tewfik 1996). Small juvenile (Sm, <150 mm shell length, S.L.), medium juvenile (Me, 150-200 mm S.L.), large juvenile (L, >200 mm S.L.), sub-adult (SA, flared lip forming but < 4 mm thick), normal adult (N, fully formed lip, prominent spines, relatively smooth outer surface) or stoned adult (S, very thick lip, worn spines, rough outer surface). Juvenile shell lengths were measured in situ using size categories marked on the 3 m PVC pole used in transect width determination. Conch were also categorized as live or dead.

Divers also noted habitat/substrate type as well as water depth. Substrate and habitat types included sand plain (SP, dominated by bare sand, sparse to moderate algal or macrophyte cover), algal plain (AP, fine mud to coarse sand dominated by green algae; *Halimeda spp., Penicillus spp., Caulerpa spp.,* etc.), seagrass meadow (SG, good macrophyte cover; *Thalasia spp., Syringodium spp.*), patch reef (PR, variety of reef morphologies dominated by large living colonies of stony corals; *Acropora spp., Montastraea spp., Diploria spp.*), coral heads (CH, single colonies of stony corals scattered amongst sand), coral rubble (CR, dead, eroded and broken coral forming patches), hard bottom (H, dominated by solid substrate often associated with GS), and gorgonian/sponge plain (GS). All data was noted on underwater slates and later transcribed onto data sheets.

Estimates of conch density were based on the mean number of conch encountered over all the transects completed at a site and extrapolated to one hectare (ha=10 000 m^2) for all size/age categories as well as total conch. Calculations of standard deviation were done using descriptive statistics tool in Corel Quattro Pro 6.0. Confidence intervals (CI, 95%) were calculated using a customized bootstrap program (WinGLFA ver. 2.0). Estimates of total abundance were calculated by multiplying density (conch/ha) in a given zone by the total area in that zone. Descriptions of population structure used the distribution of the six size/age categories (Sm., Me, L, SA, N, S). Habitat utilization and preferences were based on densities of conch in the 8 substrate/habitat types described as well as by three water depth zones (0.0-11.9 m, 12.0-17.9 m, 18.0-23.9 m).

Recent exploitation (fishing mortality, **F**) was estimated using ratio of live to dead conch encountered, the amount of exported conch from Natural Resource Conservation Authority (NRCA) data, as well as decline in conch abundances between surveys. Live to dead conch ratio was used to calculate survival and ultimately fishing mortality (**F**) as follows:

$\mathbf{F = -ln(S)/t}$,   equation ***A***

where **S** = survival rate (number live/number live+dead) , **t** = time (years). The method using declines in conch abundance used standing stocks of exploited biomass, normal plus stoned adults (N+S) plus recent recruitment (1994-1997), as follows:

$\mathbf{F= [-ln (Nt_1)/(Nt_2)]/(t_2 - t_1)}$, (Sparre 1992, p120), equation ***B*** where **N** = exploitable population , **t** = time (years), assuming **F = Z** (very small natural mortality in adult conch). Recent (1994-1997) and future (1997-2000) recruitment estimates were made using the exponential decay model:

$\mathbf{Nt_2 = Nt_1\ Exp[-M\ (t_2\text{-}t_1)]}$, (Sparre 1992, p113), equation ***C***

where $\mathbf{N(t_x)}$ =cohort abundance at time $\mathbf{t_x}$, **M**=natural mortality, **t**=time (years), to calculate juvenile survivorship to normal adult category from standing stocks of juveniles (Sm, Me, L) and subadults found during the 1994 and 1997 surveys respectfully. Table 6 gives estimates of **M** and **t** used in calculations.

Finally estimates of maximum sustainable yield (MSY) were calculated using the empirical formula defined by Gulland (1971) which assumes that the stock is in a virgin state and that some estimate of overall biomass and natural mortality are available. It is argued that in 1994 the commercial exploitation was only recent and had not extended appreciably into the 20-30 m zone: thus, the stock in that strata was largely in a virgin state. The formula reads as follows:

MSY = X M Bv, (Sparre 1992, p260), equation ***D***

where **X** is a multiplier, **M** is the instantaneous natural mortality, and **Bv** is the exploitable virgin stock biomass. It is assumed that the X multiplier is 0.5 when fishing mortality (F) equals natural mortality (M) under optimum exploitation. Caddy and Csirke (1983) showed that this does not apply to many stocks especially prey species such as shrimp. It was concluded that MY may be overestimated by 2 to 3 times using X = 0.5 and that the multiplier should be reduced to 0.2 (Beddington and Cooke 1983). Kirkwood et al. (1994) also found that the X multiplier ranged between 0.1-0.3. The natural mortality (M) rates calculated for queen conch over the life span range from 2.12 (juveniles, Appeldoorn 1988a) to 0.433 (normal adults, Rathier and Battaglya 1994). Natural mortality values of 0.1-0.4 were used emphasizing the decreasing M values for conch over the exploited phase (adults) (Appeldoorn 1988b) and high abundance of stoned (very low natural mortality) conch on the Bank. Virgin exploitable biomass (**Bv**) was based on the density of adults (N + S) in the 20-30 m zone in 1994 (203 conch/ha) applied to the total area of the bank within 0-30 m (203 conch/ha * 608 700 ha). The total number of individuals was transformed to meat weight using a conversion factor for 50% clean (8.14 conch/kg: Tewfik 1996), 15 180 MT.

3.0 Results

A total of 22 sites were examined in the two zones; five in Artisinal zone (Table 1) and 17 in 10-20m zone (Table 2). A total of 18 transects (5400 m^2) and 50 transects (15000 m^2) was sampled in the Artisinal and 10-20 m zones respectfully. Live conch were seen in all but one site (7) and even there dead conch were found. Although living conch were seen consistently at all sites the range of densities within transects and among sites created large standard deviations

(Table 1,2) The mean density (number/ha) (95% confidence interval) of total live conch (juveniles and adults) in each management zone was: Artisinal, 316 (206-722); 10-20m, 513 (273-784) (Table 3). Table 3 also gives the mean density (number/ha) in each zone for each size/age category. The total abundance (95% confidence interval) of live conch in each zone was estimated as 11.7 million (7.6-26.7) in Artisinal zone, 103.4 million (55.1-158.1) in the 10-20m zone (Table 3).

The population structure using mean density figures of live conch per hectare in the Artisinal zone (Figure 3) was 70.3% juveniles (including sub-adults) and 29.7% adults. The largest category in the Artisinal zone was Me (29.2%) followed by N (20.7%), Sm (15.3%), SA (15.3%), L (10.5%), and S (9.0%). In the 10-20 m zone (Figure 3) the population was seen as 90.7% juveniles (including sub-adults) and 9.3% adults. The largest category in the 10-20 m zone was Sm (55.5%) followed by Me (27.5%), N (6.2%), SA (5.6%), S (3.1%), and L (2.1%).

With respect to habitat live conch were found in highest densities at Algal plain (AP) sites in all size/age categories (Table 4, Figure 4). Hard plains (CR,H,GS) tended to represent habitats of lowest live conch densities in all but L and SA where the lowest densities were in sand plain habitats (Table 4, Figure 4). Water depths of 18.0-23.9 m represented areas with the highest densities of Sm and Me juveniles and conversely the lowest densities of all other size/age categories (Table 4, Figure 5).

Dead conch were found at all sites except site 39. The density of dead conch averaged 646 conch/ha, 91.8% (593 conch/ha) being N + S adults, in the Artisinal zone (Figure 6) and the ratio of live to dead exploitable size/age categories (N+S) was 1:6.4 (93:593 conch/ha). Given the accumulation of shells over the hard bottom substrates that dominate the Artisinal sites and the subsequent extended burial/decay times for shells it was not possible to estimate recent exploitation for this zone. In the 10-20 m zone density of dead conch averaged 135 conch/ha, 63.0 % (85 conch/ha) being N + S adults and 27.6% (37 conch/ha) being unknocked small juveniles (Figure 6). The ratio of live to dead (exploited) conch was 1:1.8 (48:85 conch/ha) in the 10-20 m zone resulting in a survival rate of 0.357. Given an observed shell burying rate of approximately 1.0 years on sand/algal plains in Puerto Rico (pers. obs.), which dominate the 10-20 m zone, a 1:1.8 live to dead conch ratio would constitute an F=1.03 (using survival rate = 0.357 and equation ***A***). This would account for 17 147 000 conch (48 conch/ha * 1.8* 201700, 69%) of the total harvest from the 10-20 m zone (see next paragraph). To account for all of the 24 795 000 conch harvested from the 10-20 m zone over the last three years the shell burial time would have to decrease to 0.69 years and subsequent fishing mortality would increase to F=1.49. The true ratio, had none been buried, would be 1:2.6 live to dead shells accounting for the 24 795 000 harvested conch (48 conch/ha*2.6*201 700 ha).

Fishing mortalities **(F)** based on the decline in exploitable (N+S) conch abundance first required the calculation of available exploitable biomass (N+S) including recent recruitment (Table 6),

1994(10-20m): Exploitable (N+S '94, 152 conch/ha * 201700 ha) + New Recruits (Table 6f, equation ***C***): 30 658 000 + 3 818 000 = **34 476 000** ***(1)***

1994 (20-30m): Exploitable (N+S '94, 203 conch/ha * 370 000 ha) + New Recruits (Table 6g, equation ***C***): 75 110 000 + 10 408 000 = **85 518 000** ***(2)***

followed by estimates of current standing exploitable biomass (N+S),

1997(10-20m): (N+S, '97, 48 conch/ha * 201700 ha) = **9 681 000** ***(3)***

10-20 m harvest '94-'97: 34 476 000 - 9 681 000 **= 24 795 000** ***(4)***

Total harvest '94-'97: 41 534 000 (5809 MT x 7.15 x 1000) - 24 795 000 ***(4)***

= **16 739 000** (assumed harvest from 20-30m '94-'97) ***(5)***

1997 (20-30m): 85 518 000 ***(2)*** -16 739 000 ***(5)***

= **68 779 000** (remainder of N+S in 20-30) ***(6)***

Final calculations of fishing mortality using equation ***B*** are as follows:

F(10-20m) = -ln(**34 476 000**/ **9 681 000**)/3 years = **0.42**

F(20-30m) = -ln(**85 518 000**/**68 779 000**)/3 years = **0.072**

An exploitation rate was also estimated using the amount of conch meat exported from Jamaica over the last three fishing seasons which was made available from NRCA (CITES permit issuing agency) records. As the majority of legally landed conch leaves Jamaica in the form of exports and all exports must be accompanied by a CITES export permit (*S. gigas* being listed on appendix II, potentially threatened) the NRCA data should give an accurate account of exploitation rates. Exports may leave in the form of various grades (Table 5) and therefore have been converted to a total of 5809 MT of conch meat (50% clean equivalent, Figure 2) which was exported over the last three years (mean=1936 MT). Conversion factors (Table 5) are based on measurements of meat weights taken at various processing plants. The 5809 metric tonnes of conch meat is equivalent to approximately 41 534 000 individual conch (using conversion of 7.15 conch/kg, Table 5). As only 24 795 000 ***(4)*** conch have been extracted from the 10-20 m zone it must be assumed that the majority of the remaining harvest (16 739 000 ***(5)***) and subsequent exports must have come from the 20-30 m zone. Exploitation rate (harvest of N+S) in the 10-20 m zone is 1.5 times that in the 20-30 m zone based on the above estimates of harvest. It should also be noted that the standing exploitable biomass (N+S) in the 20-30 m zone ***(2)*** is 2.5 times greater than that in the 10-20 m ***(1)***.

Recent recruitment of approximately 9 N conch/ha does not account for the overall net increase (73 conch/ha to 93 - 9= 84 conch/ha) of exploitable standing biomass (N+S) in the Artisinal zone. Present standing juvenile biomass (Table 6c) was used to calculate a total of 20

500 000 new recruits (2867.2 MT) (Table 6d) being available in the year 2000. This however was calculated only for 0- 20 m as 20-30 m zone was not surveyed.

Table 7 and the associated figure give a range of MSY estimations. These estimates use equation ***D*** and a standing exploitable virgin biomass of 15 180 MT. It is felt that an MSY of 1366 MT annually is the most optimistic estimate using liberal values of both X (0.3) and M (0.3). If exploitation is concentrated in the 0-20 m zone (as evidenced by 1.5, harvest based on exports, to 5.8, F based on abundance, times higher exploitation in the 0-20 m zone) the estimate of MSY would be proportionally reduced by the percent area being exploited. Thus for the 0-20 m area the MSY would be [1366 MT * 0.39 (0-20/0-30) =] 533 MT.

4.0 Discussion

The overall density and abundance of conch on Pedro Bank are again at least 10 times that reported from other areas in the region (8.7 conch/ha, Wood and Olsen; 24.6 conch/ha, Smith and Neirop 1984; 8.1 conch/ha, Torres Rosando 1987; 2.9 conch/ha, Berg et al 1992; 12.3 conch/ha , Friedlander et al 1994; 53.6-96.0 conch/ha, Stoner and Ray 1996; 29 conch/ha, Appeldoorn 1997; 14.6 conch/ha, Tewfik et al 1997) and are on the same order of magnitude reported during the first survey. The critical change however occurs in the distribution of density amongst the six size/age categories. A comparison of distribution of conch from the 1997 (Figure 3) and 1994 surveys (Figure 7) quickly reveals that densities of normal and stoned conch (exploitable portion of the stock) have decreased 50% (from 64 conch/ha to 32 conch/ha) and 82% (from 88 conch/ha to 16 conch/ha) respectfully in the critical 10-20 m zone where the majority of commercial harvest is thought to take place. Similarly the density of stoned conch in the Artisinal zone have also decreased by approx. 50% although a 3 times increase is noted for normal adults (Figure 3).

The other significant change in size/age class distribution is in the small and medium juveniles which have increased dramatically in both the Artisinal and 10-20 m zones (Figure 3). The reason(s) for this marked increase can only be speculated on and may be due to the availability of habitat and food resources for incoming larvae as a result of Normal and Stoned adults being removed by harvest or may simply be an unusually high settlement of larvae in a natural cycle that may only occur every so often (>5 years). If such high levels of larval settlement are regular events (every 1-3 years) and subsequent juvenile survivorship is high it would be a welcome relief to the high rates of exploitation seen in the adult categories.

Although the 1997 survey covered only a portion of the stations surveyed in 1994, all analyses are based on a comparison to all stations sampled in 1994. Because the present stations were located only within a precision of one nautical mile of the 1994 stations, it is felt that in actuality, the exact locations were not re-sampled. This simplifies statistical analysis by obviating the use of methods based on repeated measures and allowing data to be considered a random sample relative to the 1994 data. This, in turn, allows the statistically valid use of all the 1994 data, thus taking full advantage of previous analyses and the greater detail that came with 1994's larger sample size; it also allows results (both for 1997 and its comparison to 1994) to be extrapolated over the entire strata surveyed. It is interesting to note, however, that comparison of the 1997 data to the subset of 1994 data taken from the same stations sampled in the present survey (Figure 8) shows that the estimates of population densities are quite similar (compare to Figure 7).

The exploitation estimates from the 10-20 and 20-30 m zones clearly show that the 10-20 m zone is being over harvested by 1.5-5.8 times. Given the significantly smaller standing exploitable biomass in the 10-20 m zone (2.5 times less N+S) the disproportionalness of the harvest in the 10-20 m zone as compared with the 20-30 m zone is extreme. This fact is critical when allocating MSY quotas based on calculations that include all areas from 0-30 m.

The distribution of conch within various habitats (Table 4) is consistent with the results of the 1994 survey with highest densities in algal plains, followed by sand plain and hard plains. Friedlander et al (1995) found coral rubble and seagrass to contain highest densities. Algal and sand plains have been described as unsuitable sites for juvenile conch (Stoner and Sandt 1991b). Perhaps the extensive algal plain habitats that exist on Pedro Bank have replaced the need or use of seagrass beds as nursery areas. Shallow seagrass beds are thought to be critical for juvenile conch in some systems (Randall 1964, Weil and Laughlin 1984, Stoner and Waite 1990). Densities in various water depths are also consistent over the two surveys with the 18.0-23.9 m zone having highest densities. This is most significantly true for small and medium size/age categories which traditionally are associated with shallow nursery sites where seagrass is abundant. Deep water sites (>18 m) have in the past been associated as deep water refugia for reproductively active adult conch (Berg 1975, Stoner and Sandt 1992).The dynamics of deepwater systems have created different preferences for habitat by the Pedro conch population but are not well defined as yet and require further study.

Although it was hoped to use the number of dead (knocked) conch and their ratio to live conch to estimate recent exploitation of the adults (N+S) the extensive period of exploitation in certain areas (Artisinal zone >10 yrs), the undefined time required to breakdown shell, and the speculated time to bury shells in soft sediments made the use of density of dead shells difficult. The large range in dead conch density and percent adult conch within those figures between the Artisinal and 10-20 m zones is largely due to extensive exploitation in the Artisinal zone which is mostly associated with harder substrates where shells remain visible for many years. Fishing mortalities of 1.03 and 1.49 were calculated based on live to dead conch ratios with 1.0 and 0.69 year burying times respectfully. An exploitation rate of 125 conch/ha (48*2.6) (N+S) over the last three years used the estimate of 0.69 years to bury shells and consequently modified the live to dead conch ratio from 1:1.8 to 1:2.6 (1/.69*1.8). This level of exploitation would therefore be consistent with exploitation rate over the last three seasons in that zone (24 795 000 conch). Experiments that would monitor dead shell decay and burial rates could assist in the estimation of exploitation rates of this nature in future surveys.

Fishing mortality estimates (10-20, F=0.42, 20-30, F=0.072) based on changes in the standing exploitable biomass (N+S) between 1994 and 1997 again emphasize that the harvest sector is removing a disproportionate percentage of conch from the 10-20 m zone. Fishing mortality estimates for the Artisinal zone are not available since a net increase in exploitable biomass appears (414 000 conch, 11 conch/ha without new recruits of 9 conch/ha). The accurate reporting of location of catch may help to increase the accuracy of fishing mortality estimates of this type in the future. Fishing mortalities based on dead conch and changes in live conch abundance are significantly different. These differences could be reconciled for by unaccounted greater recruitment, increasing F values from standing stock calculations, or by increasing time for shells to bury (2.0 yrs) thereby decreasing F values from dead shell densities.

Estimates of exploitation rates from NRCA export data assume that the majority of the catch is exported and accuracy of reports which include total weight and grade of processing. The processing grade is critical so that the appropriate conversion factors (Table 5) are used. The calculation of conversion factors is also dependent on accurate meat weight data collection in the plants. At this time only the 50% grade can be confirmed from sampling of 2700+ meats at various plants. Other conversion factors are largely extrapolated based on earlier studies by Tewfik (1996). The results of poor reporting and poor conversion factor calculations (inability of management authority to access processing plants) significantly contributes to the problems of over exploitation of the stock.

Recent and future recruitment (juvenile survivorship, Table 6) of conch to the normal adult size/age class were based on estimates of M and t from other areas (Appeldoorn 1988). Despite this it is felt that juvenile survivorship figures are reasonable and these estimates assisted in the understanding of present densities of normal and stoned conch. The only major conflict encountered in these calculations was the inconsistency in the Artisinal zone. The estimated juvenile survivorship of 9 conch/ha of new normal individuals entering the exploitable biomass does not make up for the marked increase in normal from 20 conch/ha in 1994 to 56 conch/ha (65-9) in 1997. Where have the additional 36 conch/ha come from especially considering that some exploitation of adult conch does occur in this zone?. It is suspected that the abundances of small and perhaps medium conch in 1994 were underestimated due to the cryptic nature (largely buried for the first year of life, emerge during the night to feed) of these size/age classes.

The use of the Gulland's estimate of maximum sustainable yield (MSY) is very well suited to fisheries that are "sparsely investigated and lightly exploited" (Sparre 1992) but have an estimate of overall exploitable biomass and natural mortality. The range of MSY estimates given in table 7 reflect the uncertainties of natural mortalities (M) that occur amongst individual ages of conch in the exploitable portion of the stock as well as the range of values for the X multiplier suggested by Beddington and Cooke (1983) and Kirkwood et al. (1994). The optimistic best estimate of 1366 MT/year is based on liberal figures for M and X as well as the fact that the exploitation should occur over the entire area of 0-30 m on an equal basis. This last assumption seems to be in some doubt given the estimates of exploited biomass (1.5 times the harvest level in 10-20 as in 20-30) and figures calculated for fishing mortality in the 10-20 (F=0.42) and 20-30 (F=0.073) m zones. Continued harvest concentrated in the 0-20 m zone would naturally lead to a reduction of MSY to a proportional figure (533 MT, 0.39*1366 MT). Strict application of Gullands' formula states that yield is maximized when the standing biomass is one-half the virgin biomass (0.5 Bv). Therefore a target density, using Bv density in 20-30 m zone, of 101 conch/ha (N+S) would have to follow. Some adjustments to this would include slightly lower densities expected in shallower areas given that conch move into deeper waters with age. Therefore the present standing stock of N+S in the Artisinal zone (93 conch/ha) seems to be on target. However the low density of N+S (48 conch/ha) in the 10-20 m zone is approximately half that required to satisfy 0.5 Bv and is a point of concern.

5.0 Conclusions

The exploitation rates (catch) over the last three years have totalled 5809 MT, averaging 1936 MT per year. Based on all available scientific data, this exploitation rate is beyond the sustainable capacity of the stock given the following: (1) The significant changes that have occurred in population densities, overall abundance, and population structure over the last three years, most clearly in the 10-20 m zone, as a result of commercial exploitation. Normal and stoned conch densities have rapidly decreased 50% (from 64 conch/ha to 32 conch/ha) and 82% (from 88 conch/ha to 16 conch/ha) respectively in the 10-20 m zone; (2) Harvest levels, mean of 1936 MT over the last three years, versus most optimistic estimates of MSY (1366 MT); (3) Optimal fishing mortality (F=0.18) compared to much higher fishing mortalities observed from levels of dead N+S conch (F=1.49) and changes in N+S abundances (F=0.42) in the 10-20 m zone; and (4) Optimal densities based on 0.5Bv (half virgin biomass, 101 conch/ha) compared with present exploitable biomass densities in the Artisinal (93 conch/ha) and 10-20 m (48 conch/ha) zones.

It has also been observed that the level of fishing mortality (catch) has not been proportionally distributed over the entire area of the Bank (0-30 m) on which earlier (Appeldoorn

1995, Tewfik 1996) estimates of MSY were based. Several calculations have been made confirming this fact: (1) Fishing mortalities, based on changes in abundance of exploitable biomass (N+S) over the last three years, are significantly different (10-20 m zone, F=0.42; 20-30 m zone, F=0.072); (2) overall harvest in the 10-20 m zone is seen to be 1.5 times as high as in the 20-30 m zone; and (3) Densities of standing exploitable biomass in the Artisinal (93 conch/ha) and 10-20 m (48 conch/ha) zones are significantly different. Disproportional harvest would mean zone specific MSYs (10-20 m, 533 MT) and eventual zone closures when standing exploitable biomass falls below sustainable levels within certain zones. It should noted that the 10-20 m zone, the area of highest production, is already at such low densities that an area closure would seem to be appropriate if the current trend continues.

The entire problem of poaching has not been addressed and is not part of any calculations thus far. All poaching would have to be added to the suspected harvest in the 20-30 m zone. MSY calculations would also have to be modified by subtracting the expected poaching from the best optimistic MSY (1366 MT) and the remaining MSY used as the total available annual quota.

Although the levels of recruitment in future seem good, based on significant increases in the abundance of small and medium juveniles, this level of recruitment can not be expected to continue. The low abundances of juveniles observed in the 1994 survey should indicate the large variations that should be expected in annual recruitment levels. It should again be emphasized that the dynamics of deepwater stocks have been very poorly investigated and further understanding of the Pedro bank stock will require the long-term commitment and cooperation of concerned and affected parties.

6.0 Recommendations

The following recommendations of management measures are made with respect to the specific circumstances of this fishery in being: an offshore, deepwater stock; industrial scale exploitation (large vessels with many divers); export driven; and the limited management and enforcement capacity of local authority (Fisheries Division). The effectiveness of any management measure is ultimately seen in compliance by all concern parities. Lack of compliance is the same as having no management measure in place.

1) Size Restrictions: The presence of a well developed shell lip (lip thickness >5mm), a feature linked to sexual maturity in conch, would be a useful regulation easily identified by divers (free, hookah, SCUBA) at sea. This lip presence would restrict harvest to sexually mature adult conch and protect juveniles and sub-adults. Although conch are removed from the shell at sea compliance with this measure could be enforced at the limited large scale landing sites. The identification of a mature verge (males) or vaginal groove (females), by trained personal, on meats processed to 50% would indicate sexually maturity and thus compliance with the shell lip minimum regulation.

Another useful and enforceable minimum size restriction available to this fishery, given that only the meats are landed at the mainland processing plants, is meat weight. Using morphometric data of conch collected at several locations on Pedro Bank the smallest tissue weight encountered among adult conch were stoned in the centre of the bank (Tewfik 1996). This minimum of 95 g multiplied by the "Dirty " category (Table 5) gives a minimum meat weight (50% clean) of 80.75 g. This minimum meat weight should be associated with a conch in a sexually mature state (ie verge or vagina groove present and well developed). By combining sexual maturity with minimum meat weight the presence of a mature shell lip is virtually guaranteed. Therefore conch divers at sea will use the shell lip minimum (>5 mm) as a guide to adhere to meat weight minimum and associated sexual maturity regulations. The stipulation of sexual maturity is important to avoid the use of large juveniles that can have meat weight in excess of 80.75 g. No meats should therefore be landed that are processed beyond 50% as reproductive structures would not be available for identification.

2) Closures: The use of a closed season (July-Oct.) will continue to protect the reproductive portion of the stock during peak breeding periods. Given the size of the bank and the apparent lack of specific nursery and breeding areas the closure of specific locations within the bank to protect such sites seems of little value.

Assuming radar coverage of the bank is possible, large areas (ie all of the bank west of 78^{o} 20' line) could be closed on a rotational basis. This would have three advantages: 1) it would concentrate effort into a more limited space, so that poaching might be more obvious, 2) it would force the fishery to fish throughout the open areas, thereby preserving stock density in given areas at levels optimum for production, and 3) stock recovery within closed areas would be possible and proceed undisturbed.

Finally use of marine reserves or protected areas, without associations to specific habitats (nursery or breeding), would create pockets of high conch production that would eventually disperse out to other unprotected areas. The mobile nature of the stock would suit this plan well, and fishers' awareness of this mobility should aid in self compliance. Ideally these protected areas would have a complete ban on fishing making enforcement simpler as well as allowing other living aquatic resources to benefit from protection. Areas in proximity to the cays and the Coast Guard station seem the most logical for the primary establishment of such protected areas. Marine reserves are necessary components of management as they address management goals not obtainable using other methods, including (but not limited to) preserving spawning stock and spawning density (especially in an "up-stream" location), providing insurance against management failure, providing control areas against which effects of fishing may be gaged, and conserving biological (especially genetic) diversity.

3) Gear Restrictions: Due to the deep nature of the stock (mean 18 m) the banning of SCUBA or Hookah gear can not be advocated as this would virtually eliminate the commercial scale harvest of the stock. Such a ban may however be effective in shallow areas (<10 m) in proximity to the Pedro cays where some free divers are presently being out competed by SCUBA and Hookah assisted divers. The preservation of shallow stocks and a traditional fishing method would be a positive result.

4) Vessel Restrictions: The limitation on maximum size of commercial scale vessels (mother boats) effectively restricts the number of divers/dories that may be deployed from that mother boat and ultimately restricts the total catch that can be secured by the vessel. The mother boats should be limited to some maximum length, storage capacity and number of divers that still allows the trip to be profitable given the conditions of the stock value.

5) Bulk Harvest Restrictions: Based on the present study an immediate lowering of the total allowable catch (TAC) to 1366 MT must be implemented and this TAC must be equally harvested over the entire area open to fishing at any given time. This is to say that a significant portion of future fishing effort must be conducted in the 20-30 m zone to prevent overfishing within the 10-20 m zone. This TAC is lower than originally planned, but is necessary given the heavy exploitation and less than adequate information provided on catch, effort, and areas fished by the conch industry. It should also be remembered that the suspected poaching must be subtracted from the TAC before quotas are allocated. The continuance of high recruitment, reflected in the current high densities of small and medium juveniles, can not be depended upon at this time.

6) Reporting and Inspections: The mandatory reporting of catch, effort, and areas fished by all commercial conch vessels is paramount to management of the stock and such information should be made available to the Fisheries Division prior to the off loading of any catch to processing plants. These catches should be subject to random inspection of meat size and sexual maturity. In addition all exports of conch out of Jamaica should also be subject to random inspection to verify process grade and total weight declared.

7.0 References

Alcolado, P.M. 1976. Growth, morphological variations in the shell, and biological data of the conch ("Cobo") *Strombus gigs* L. (Mollusca, Mesogastropoda). Academia De Ciencias De Cuba, Instituto De Oceanologica, Serie Oceanologica No. 34. (translation)

Appeldoorn, R.S. 1988. Ontogenetic changes in the natural mortality rate of queen conch, *Strombus gigas* (Mollusca: Mesogastropoda). Bull. Mar. Sci. 42: 159-165

Appeldoorn, R.S. 1994. Queen conch management and research: Status, needs, and priorites. In: Queen conch biology, fisheries, and mariculture. R. S. Appeldoorn and B. Roodriquez, Eds. Fundacion Cientifica Los Roques, Caracas, Venezuala. pp 301-320.

Appeldoorn, R.S. 1995. Stock abundance and potential yield of the queen conch of Pedro Bank. Univ. Puerto Rico/Fisheries Div. Jamaica. 30 pp.

Appeldoorn, R.S. 1996. Stock abundance and potential yield of the queen conch resource in Belize. CFRAMP and Belize Fisheries Department. 30 pp.

Beddington, J.R. and J.G. Cooke. 1983. Potential yield of fish stocks. FAO Fish. Tech. Pap. 242. 47 pp.

Berg, C.J.,Jr. 1975. Behaviour and ecology of conch (Superfamily Strombacea) on a deep subtidal algal plain. Bull. Mar. Sci. 25: 307-317.

Berg, C.J.,Jr. and D.A. Olsen. 1989. Conservation and management of queen conch (*Strombus gigas*) fisheries in the Caribbean. In: Marine invertebrate fisheries: their assessment and management. J.F. Caddy, Ed. John Wiley & Sons, New York.

Berg, C.J.,Jr., F. Couper, K. Nisbet, J. Ward. 1992. Stock assessment of queen conch, *Strombus gigas*, and harbour conch, *S. costatus*, in Bermuda. Proc. Gulf Caribb. Fish. Inst. 41: 433-438.

Brownell, W.N., C.J. Berg, Jr., and K.C. Haines. 1977. Fisheries and aquaculture of the queen conch, *Strombus gigas*, in the Caribbean. FAO Fish. Rep. 200: 59-69.

Caddy, J.F. and J. Csirke. 1983. Approximations to sustainable yields for exploited and unexploited stocks. Oceanogr. Trop. 18: 3-15.

Chakallal, B. And K.L. Cochrane. 1996. The queen conch fishery in the Caribbean - An approach to reponsible management. Pres. at Int'l. Mtg. On Queen Conch Fishery, Puerto Rico, July 29-31,1996. 18 pp.

Dolan, P. 1972. Genesis and distribution of recent sediments on Pedro Bank, south of Jamaica. Ph.D thesis, University College, London. 232 p.

Friedlander, A., R. Appeldoorn, and J. Beets. 1994. Spatial and temporal variations in stock abundance of queen conch, *Strombus gigas*, in the U.S. Virgin Islands. In: Queen conch biology, fisheries and mariculture. R.S. Appeldoorn and B. Rodriquez, Eds. Fundacion Cientifica Los Roques, Caracas, Venezuela. pp.51-60.

Gulland, J.A. 1971. The fish resources of the ocean. Fishing News (Books) Surrey, England. 255p.

Kirkwood, G.P., J.R. Beddington, and J.A. Rossouw. 1994. Harvesting species of differnet life spans. In: Large-scale ecology and conservation biology. P.J. Edwards, R. May, and N.R. Webb Eds. Blackwell Scientific Publ., Oxford. pp 199-227.

Kong, G.A. 1997. The Jamaica queen conch management plan: A review and critical analysis. Graduate Research Project, Marine Affairs Program, Dalhousie University, N.S. 133 pp.

Mahon, R., G.A. Kong, and K.A. Aiken. 1992. A preliminary assessment of the conch fishery on the shelf and banks off the south coast of Jamaica. CARICOM Fishery Research Document No. 8.

Munro, J.L. and R. Thompson. 1973. Ch 3: Areas Investigated, Objectives, and Methodology. In: Caribbean Coral Reef Fishery Resources. ICLARM Studies and Reviews 7 (J.L. Munro. ed.), 15- 19.

Randall, J.E. 1964. Contributions to the biology of the queen conch, *Strombus gigas.* Bull. Mar. Sci. Gulf Caribb. 14: 247-295.

Rathier, I. and A. Battaglya. 1994. Assessment of the Martinique queen conch fishery and management prospectives. In: Queen conch biology, fisheries, and mariculture. R. S. Appeldoorn and B. Roodriquez, Eds. Fundacion Cientifica Los Roques, Caracas, Venezuala. pp 29-50.

Smith, G. B. and van Nierop, M. 1984. Distribution, Abundance and Potential Yield of Shallow Water Fishery Resources of the Little and Great Bahama Banks. UNDP/FAO Fish. Dev. Proj. BHA/82/002:1-78.

Spare, P, E.. 1992. Introduction to tropical fish stock assessment, Part one-Manual. FAO Fish. Tech. Paper. 306/1, Rev. 1. Rome.

Stoner, A.W. and J.M. Waite. 1990. Distribution and behavior of queen conch *Strombus gigas* relative to seagrass standing crop. Fish. Bull., U.S. 88: 573-585.

Stoner, A.W. and V.J. Sandt. 1991. Experimental analysis of habitat quality for juvenile queen conch in seagrass meadows. Fish. Bull., U.S. 89: 693-700.

Stoner, A.W. and V.J. Sandt. 1992. Population structure, seasonal movements and feeding of queen conch, *Stombus gigas*, in deep-water habitats of the Bahamas. Bull. Mar. Sci. 51: 287-300.

Stoner, A.W. and M. Ray. 1996. Queen conch, *Strombus gigas*, in fished and unfished locations of the Bahamas: effects of a marine fishery reserve on adults, juveniles, and larval production. Fish. Bull. 94:551-565.

Tewfik, A. 1996. An assessment of the biological characteristics, abundance, and potential yield of the queen conch (*Strombus gigas* L.) fishery on the Pedro bank off Jamaica. M.Sc. thesis, Acadia University, Wolfville, NS, 139 pp.

Tewfik, A. 1997. Life history, ecology, fisheries, stock status, and management measures of the queen conch, *Strombus gigas*.In: Lobster and conch subproject specification and training workshop proceedings, 9-12 October, Kingston Jamaica. CARICOM Fish. Res. Doc. No. 19. pp 84-117.

Tewfik, A., H. Guzmán & G. Hácome 1998. Assessment of the queen conch, *Strombus gigas*, (Gastropoda: Strombidae) population in Cayos Cochinos, Honduras. Rev. Biol. Trop., 46. Supl. (4): 137-150.

Torres Rosado, Z.A. 1987. Distribution of two mesogastropods, the queen conch, *Strombus gigas* L., and the milk conch, *Strombus costatus* Gemlin, in La Parguera, Lajas, Puerto Rico. M.S. Thesis, Univ. Puerto Rico, Mayaguez, PR. 37 pp.

Troadec, J-P. 1977. Methodes semi-quantitatives d'evaluation. FAO Circ. Peches. 701: 131-141.

Weil, E.M. and R.G. Laughlin. 1984. Biology, population dynamics, and reproduction of the queen conch *Stombus gigas.*Linne in the archipielago de Los Roques national park. J. Shellfish Res. 4: 45-62.

Wood, R.S. and D.A. Olsen. 1983. Application of biological knowledge to the management of the Virgin Islands conch fishery. Proc. Gulf Caribb. Fish. Inst. 35: 112-121.